# Joint Data Link Warfare

## ABSTRACT

Data links are integral to warfare. Data links have been manifested in different forms since antiquity for the coordination of warfare. In the last four years, however, data links have once again gained focus due to the successful deployment of data-linked systems in Operation Iraqi Freedom as a force multiplier. Furthermore, data links have enabled joint operations between different force elements. This has raised the importance and prominence of data link integration.

In this paper, we discuss the utility of data links in the context of joint warfare using open source information. Different data link architectures are briefly discussed. Drawing insights from network science, the study of representations of physical, biological and social phenomena leading to predictive models, we derive conceptual data link architecture for unified operations in a non-linear battlespace.

**Dr Yeoh Lean Weng**
**Daniel Chia Kim Boon**

# Joint Data Link Warfare

## INTRODUCTION

A data link essentially enables two parties to communicate messages. Data link is not a modern conception. For example, smoke signals were used by Native American Indians to convey messages across a distance. The mechanism for creating the smoke signals is fairly simple: it requires only a fire and blanket. The signal has to be visible and is usually situated on top of a hill or mountain. Confidentiality is achieved since the smoke signals are devised privately and are probably context specific. (This is similar to a "one-time" pad.)

This simple example reveals some salient characteristics of a data link:

a. It must enable collaboration across a distance.
b. It must ensure secrecy of information.
c. The message to be conveyed must be clear and easily understood by the communicating parties.

Implicitly, the data link devised by the Native American Indians can help maintain the stealth of intended receivers, and therefore help create the element of surprise in a military context.

Ancient techniques for establishing rudimentary data links were not limited to smoke signals and fire beacons. Signalling mirrors were also used to convey messages. According to Murray (2004), the emperor was alerted to Marco Polo's arrival in 13th century China through a series of sunlight signals reflected off mountaintops along his route.

Heliographs, tripod-mounted sunlight-reflecting devices which convey messages composed of dashes and dots to a designated target at a distance, were used by the British in the North Indian and Afghanistan military campaigns in the 19th century.

An account of a modern day data link, Link 16, given by Kopp (2004) reveals surprising similarities in the use context of data links. Most of the Link 16 terminals were originally operated in a receive-only mode (cf. Native Indian scouts hiding in a forest) and the signals were broadcast through an Airborne Warning and Control System (cf. mountaintop fire and smoke) controlling the fighter aircraft with the Link 16 terminals.

## WHAT HAS CHANGED?

It is not difficult to visualise how data links are used for situation awareness and synchronisation of actions both in ancient and contemporary times. While data links appear to have evolved over time, they may have changed fundamentally.

A phenomenon widely associated with "inverting the pyramid" is occurring. This means that the business of sharing secret messages is no longer limited to a few. Instead, it can involve a lot more participants. This requires creating capacity in the form of wireless and wired networked infrastructure. Furthermore, it is insufficient to achieve secrecy only; integrity and authenticity are now equally important.

Ancient data links have very little information-carrying capacity. They limit the information richness. With advances in sensors, it is now possible to digitise the battlespace. An unambiguous digitised battlespace can be formed with the help of a modern data link that enables every object, both friend and foe, to be clearly identified, tracked, and if necessary, engaged. (This is not the case in the examples mentioned earlier.)

The definition and design of a data link has to capture a wider spectrum of operational contexts, functions and processes. It has also to be synchronised across different services or units to achieve a degree of integration and operational effectiveness. For example, an air strike should not result in fratricide and should not slow the advance of ground mechanised units; instead, the air strike should reinforce and enhance the mobility of the mechanised forces. In order to achieve this, both land and air elements are required to share a common data link capability. This common capability provides ease of integration of all necessary force elements and enables a shorter warfighting cycle to be achieved. Thus, the modern data link is engineered to support a very rich picture of the battlespace and at the same time reduce the synchronisation time of all warfighting elements.

Next, we examine the significance of effective cross-service (or joint) data links. This is illustrated by using two land-air integrated warfare scenarios: German Blitzkrieg in World War II and Operation Iraqi Freedom (OIF).

## GERMAN BLITZKRIEG

Blitzkrieg is German for “lightning war” or “flash war”. The concept revolves around the coordination of tanks, air power, and artillery in a concerted effort to breach an adversary’s line of defence. It is believed that a rapid breach followed by penetration deep into the enemy’s rear, destroying logistics and vital command and control centres, should disrupt the enemy’s battle rhythm. The ensuing shock and surprise would then provide the conditions for encircling the enemy forces and crushing them. This is illustrated in Figure 1.

The ability to coordinate land and air forces for the breach and subsequent rapid advance proved crucial but difficult. Historians have credited Heinz Guderian with developing the solution to this problem by equipping tanks, artillery and the air force with High Frequency (HF) radio equipment for communications. As described by Fiedler (2004), Guderian had worked out techniques to leverage the Near Vertical Incidence Sky-wave mode of HF propagation. This enabled the German ground forces to communicate over a large area of operations on the halt and on the move, as well as with the air force. The FuG-10 HF radio with both monopole and loop antennas was the mainstay of German Blitzkrieg communications.

Tactics evolved to support the ground to air coordination. Air liaison detachments were deployed to the ground forces to pass requests from the ground to the air and receive reconnaissance reports. This was an early form of close-air support (CAS).

Although a rudimentary CAS system was established, the Germans did not train to guide aircraft onto the targets. Furthermore, not all tanks were equipped with HF radios. Only the command tanks had both the ability to transmit and receive. The fleet comprised mainly HF radios in receive mode. Thus, the “CAS network” was primarily a “Command and Control” (C2) net. Situation awareness was mainly achieved through voice.

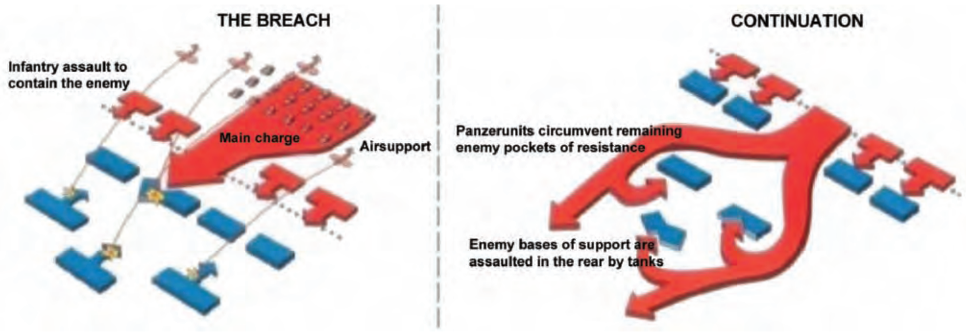

*Figure 1. (Left) Tanks breaching an enemy line with support from dive bombers (German “Stukas”). (Right) Forces penetrate deep into enemy rear to destroy bases of support. (The Origin of Blitzkrieg - WWI, n.d.)*

The new concept, tactics and technology for providing ground-to-air coordination proved successful in the invasion of France in 1940 and up to the early stages of the German invasion of Russia in 1941. Despite the innovation of tactics and technology, many problems continued to plague combined air and ground operations. The ground officers saw air support as a means to conduct mass fire at critical points, overcoming the lack of artillery; the smaller aerial bombs used also meant that roads and other transport infrastructure would be left fairly intact, a condition necessary for continued force progression into the enemy's rear. The air officers contended that distinguishing friend from foe would be difficult, and furthermore, targets on the ground engaged in combat would be dispersed and concealed, diminishing the effects of air firepower (Close Air Support, n.d.).

Essentially, both air and land elements lacked a common recognised ground picture. This was compounded by a lack of an effective data link. For example, the Germans had to mark the ground with symbols to signal to air fighter-bombers how far the ground forces had progressed. Evidently, the measure was intended to prevent fraticides, reinforcing the observation that there was a lack of situation awareness and effective data link capabilities.

## OPERATION IRAQI FREEDOM

Fast forward 60 years later. The battleground has changed from Europe to the Middle East. The US-led coalition force has launched OIF. Unlike the Persian Gulf War and Operation Enduring Freedom in Afghanistan, the US did not launch a lengthy aerial bombardment and amass significant forces before launching the ground campaign. Instead, General Tommy Franks envisaged a coordinated, simultaneous land-air campaign. Following the Blitzkrieg concept, the US forces would bypass the major cities and avoid fighting Iraqi Military Units. The centre of gravity was the capture of Baghdad. Capturing Baghdad would deal a heavy psychological blow to the morale of Iraqi military resistance.

Another objective was to minimise collateral damage to facilitate post-war reconstruction, especially to the economic infrastructure of Iraq, such as the oil rigs and wells. The campaign imperative was speed and the means to facilitate rapid ground manoeuvre was through battlespace shaping, i.e., Corp CAS. In particular, as V Corp lacked the artillery pieces to support division battlespace shaping, i.e., Multiple Launch Rocket System (MLRS) to suppress enemy air defences, Central Command made the decision to distribute Air sorties to V Corp through the Coalition Forces Land Component Commander (Kirkpatrick, 2003).

The US identified three types of CAS:

Type 1: The controller can see both the target and the aircraft and directs the aircraft attack on the target.

Type 2: The controller can neither see the target nor the aircraft but directs the attack on the target through intelligence inputs.

Type 3: Same as Type 2 but occurs in a situation where it is assessed to have a low risk probability of fratricide.

For Type 1 CAS, a simple point-to-point communications capability may suffice. Type 2 and 3 CAS require shared situation awareness and common data link capabilities. In OIF, only six percent (Kirkpatrick, 2003) of CAS was Type 1. This demonstrates the critical requirement all three elements - the intelligence input, such as from Unmanned Aerial Vehicles (UAVs), the Joint Tactical Air Controller (JTAC) and the engaging aircraft - have the same situation awareness of the target and its environment.

The challenge of CAS was further compounded by two other factors:

a. The battlespace was non-linear and CAS was required in "killboxes" that were closed due to the presence of friendly forces.

b. After Operation Desert Storm, the Iraqis studied American tactics and adopted asymmetric strategies to reduce the qualitative edge of superior American technology. They would disperse into smaller units and seek concealment in vegetation and urban areas, changing location frequently every four to eight hours, usually in bad weather or in darkness.

These factors meant that the blue force had only a short window of opportunity to engage the enemy and it had to do so in the presence of its own forces without fraticides. In the past, this could mean withholding action and engaging only when coordination with own forces was achieved. Now, the forces could operate in a self-synchronised manner.

Some evidence shows that a data linked environment was conducive for CAS despite the challenges. For example, just after 10 days, the Medina Division, reinforced by the Hammurabi Republican Guard Division, was reduced to an assessed strength of 29 percent from an initial assessed strength of 96 percent (Kirkpatrick, 2003).

Urban CAS also achieved impressive results. By the end of the war, urban CAS missions had destroyed 105 bunkers, 225 buildings and 226 targets which included aircraft, command posts and mobile C2 equipment.

## OPERATION IRAQI FREEDOM CAS VS GERMAN BLITZKRIEG

Proponents of land-air integration such as Guderian believed that effective data link is the key to land-air integration. The results of OIF have vindicated this belief. It is also clear that superior air power led the Iraqi military to adopt asymmetric strategies, making them potentially more difficult to engage as targets. In this aspect, officers of the Luftwaffe were right. Even with precision weaponry, which is similar to the idea of using smaller aerial bombs for CAS in WWII, it would not overcome asymmetric strategies targeted to avoid the brunt of airpower.

The ability to detect targets using UAVs and other real-time and near real-time intelligence sources was crucial to bringing precision weaponry to bear. In urban CAS, delayed fused Joint Direct Attack Munitions enabled targets to be attacked with low collateral damage. Such attacks were carried out after sensors such as UAVs had detected and tracked the targets, and sometimes decisions were made to defer a strike to reduce fratricides, collateral damage and civilian casualties. This circumvented asymmetric strategies such as dispersion and concealment.

Closing sensor to shooter loops with precision and with rapidity differentiated the OIF CAS from German Blitzkrieg land-air coordination. OIF CAS was precise because all objects were digitised and de-conflicted before an engagement. This was a result of real-time blue and red force tracking through a myriad of sensors integrated using near real-time data links.

The sensor to shooter loops were shorter because the sensors and shooters were tightly integrated through data links in many cases. A combination of video, situation awareness and C2 data links created a real-time collaboration environment for prosecuting Type II and III CAS targets. Usually, the environment is highly localised and supports a few nodes (a sensor-C2-shooter system), reflecting a near optimal pairing of sensors and weapons to target.

In effect, airpower was reinforced; the integration of a myriad of sensors, intel analysts, planners and decision-makers using data links reinforced the effective use of air power.

In retrospect, the Germans' inability to direct aircraft on targets in WWII was a critical gap in joint land-air integration capabilities. OIF appears to have closed this gap admirably (when the weather was good) with its system of data links. This is indeed a tribute to 60 years of remarkable progress made in data links.

## OPERATION IRAQI FREEDOM DATA LINKS

The OIF data links deployed were a system of multiple data links. Unlike the German system in WWII, it was not simplistic voice communications over HF. It depended on a networking of a handful of data links. Some of these are:

a. Common Data Links (CDLs) used for down linking sensor information to Ground Control Stations and C2 nodes. They are used to support exchange of Intelligence Surveillance Reconnaissance (ISR) information and employed mainly on manned ISR platforms.

b. Tactical Common Data Links (TCDLs), a part of the CDL family, used to equip unmanned platforms such as UAVs used in ISR applications.

c. Link 16 which is the US Department of Defense's primary Tactical Data Information Link (TADIL) based on J-series messages. It is used for C2 messages and air-to-air assets i.e., surveillance tracks, Electronic Warfare, weapon coordination, etc. It supports a wide area of operations (300 nm diameter).

d. The Enhanced Position Location Reporting System (EPLRS) / Situation Awareness Data Link (SADL) which complements Link 16 by providing the ground situation awareness picture. Aircraft equipped with SADL can also share air surveillance tracks and C2.

e. Video Data Links which provide information / video downlinks from UAVs and Litening Pods (on F16s and F15s) to specific JTACs and/or Special Operations Forces (SOFs) with special receivers.

Of the four data links, EPLRS played an important role for CAS because it was able to display the five closest friendly units within proximity, regardless of the target position. This was critical as the Blue Force Tracker (BFT) provided a non real-time update of Blue Forces' position with refreshes occurring approximately every five to 10 minutes. The information from BFT could not be used to gauge the accurate position of a unit to avoid fratricides.

The video downlinks from UAVs and video pods gave JTACs and SOFs a positive identification of a target. It also enabled the JTACs and SOFs to guide shooters such as F16s and F15s to the targets. Battle Damage Assessment (BDA) through the video downlinks was also instantaneous, enabling a faster decision to re-strike if necessary.

While EPLRS and video data links provided the capability for precise and rapid decentralised execution, the suite of CDLs, TCDLs and Link 16 provided the means for integrating intelligence with C2, enabling centralised control and the efficient allocation of resources, such as weapons and sensors to target pairing.

The increase in the sophistication of data links enabled integration and operational effectiveness. However, it came with a price. The Germans in WWII relied mainly on HF radios for communication. This entailed the same frequency and waveform operations. The advantage was greater manageability and unquestioned interoperability across land-air elements. OIF used different data link types. Consequently, for interoperability, "gateways" were required. For example, integrating Link 16 and EPLRS/SADL required the Transparent Multi-Platform Gateway (TMPG). The TMPG translated Link 16 TADIL-J messages to SADL type messages.

The different types of data links have created a situation where gateways have become a necessity. The gateways can be deployed on ground platforms, such as the BUG-E, or airborne platforms such as the KC135 ROBE. The manageability, mobility, persistence and survivability of these platforms have to be factored into the mission equations for success. Recognising the problem, the US has embarked on the Joint Tactical Radio System (JTRS). A key piece of technology is the Wideband Networking Waveform (WNW). This will be a common capability to enable cross-service integration. The JTRS will harmonise the incompatibilities and resolve some of the issues. However, because the JTRS programme has placed too much emphasis on legacy waveforms, backward compatibility and replacement of legacy radio systems, it is experiencing cost overrun and schedule slips.

The programme has to be structured around the WNW but with interoperability with fewer legacy waveforms. This also means that gateways will be necessary in the interim to operate with legacy radio systems.

A multi-data link environment would seem inescapable. With the current emphasis on joint interoperability, this means gateways on the ground, in the air and on ships. These gateways are a current reality but they do not promote agility and nimbleness. Very often, they have a large footprint, i.e., US ROBE and BUG-E which is counter to mobility, low-signature and survivability

Should cross-service integration comprise a system of multiple data links interconnected by gateways? Should it be one with greater commonality, and therefore, reducing the number of gateways? Which is more efficient and effective?

## AN EFFECTIVE JOINT DATA LINK ARCHITECTURE CONCEPT

The land-air integration is but one example of cross-service, integrated operations. In the nomenclature of network centric architecture given by Dekker (2005, Architecture D), the "joint" architecture is the most complex for data link solutioning. This is due to the complex matrix of information exchange requirements among platforms and also due to the heterogeneity of the platforms, which imposes different requirements on the data links, i.e., terrain, speed etc.

Furthermore, it is expected that the joint network-centric architecture will have a richer interconnectivity matrix as more unmanned sensors and weapons which are harmonised with manned systems are introduced . This integrated system of systems, conceived to shorten the engagement cycle, will create new demands on data links in terms of bandwidth, latency and range.

These systems will initially be few, as they have to undergo a phased transition of experimentation, integration and operational transformation before they are cost-efficient for mass adoption. This process leads to high demands for such assets and their products, i.e., sensor imagery, video, etc. Joint access to such products, whether in their raw or processed form, will be vital to creating an accurate common operational / tactical picture. The access has to be sustained even while on the move without limiting the operations tempo. This leads inevitably to the development and research of ad hoc networks. In this approach, the proponents frame the problem of data links around ad hoc, mobile networking capabilities.

An example of this approach is given by the US Wideband Networking Waveform which is currently developed to provide advanced ad hoc networking capabilities for a joint networking, data-linked environment. Most proponents of ad hoc networking envision a network of seamlessly connected nodes with multi-hop capabilities and autonomous routing scaling to thousands of nodes. In examining the conditions of joint connectivities, an ad hoc networking capability is necessary but not sufficient to achieve effective and optimal data link capabilities. We may draw some insights from scale-free network research.

In 1998, physicist Albert-Laszlo Barabasi mapped the World Wide Web using a web crawler (Scale-Free Network, n.d.). He found that the Web did not resemble a random, distributed network, against conventional wisdom. Instead, the web exhibited many well-connected nodes. Unlike random, distributed networks, the proportion of well-connected nodes does not diminish as more nodes are added, but rather, remains constant. Barabasi coined the term "scale-free networks" to

| | Value of Kawachi Process Parameter *p* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **0** | **0.02** | **0.05** | **0.1** | **0.2** | **0.5** | **1** | **2** |
| Average Distance *(D)* | 4.14 | 3.67 | 3.42 | 3.17 | 2.84 | 2.61 | 2.55 | 2.44 |
| Clustering Coefficient *(C)* | 0.50 | 0.47 | 0.44 | 0.40 | 0.32 | 0.20 | 0.17 | 0.23 |
| Node Connectivity *(K)* | 4.00 | 2.99 | 2.78 | 2.50 | 1.93 | 1.20 | 1.01 | 1.00 |
| Symmetry Ratio *(r)* | 1.56 | 3.32 | 3.70 | 4.06 | 4.56 | 4.74 | 4.65 | 4.48 |
| Performance Score *(S)* | 0.842 | 0.850 | 0.863 | 0.882 | 0.903 | 0.897 | 0.904 | 0.924 |
| Number of Hubs | 0 | 0 | 0 | 0 | 0.01 | 0.14 | 1.33 | 3.39 |

*Figure 2. Performance Score of Scale-Free Networks (Dekker, 2005)*

represent this specific class of networks. It turned out that scale-free networks describe a fairly large spectrum of networks, including power grids, social networks and gene-to-gene interactions.

Several properties of scale-free networks interest us:

a. Scale-free networks are more resilient to errors than random, distributed networks. Since data transfers in a wireless medium are sensitive to errors (more errors lead to lower data throughput), scale-free networks have an advantage.

b. Although scale-free networks are resilient to random errors, they are vulnerable to direct attacks on the "hubs".

c. Research indicates that removing a high-capacity, direct link to a "hub" reduces the value of the network more than removing long range but lower-capacity links.

The author has performed some preliminary studies on adapting the ideas of scale-free networks to wireless ad hoc networks (Chia, Tri & Su, 2006). One possibility is to adopt diversity techniques to reduce the vulnerability of direct "hub" attacks. Thus, in theory, a scale-free network could be made robust to both random errors and deliberate attacks.

It must be emphasised that scale-free networks are different from ad hoc networks in the sense that ad hoc networks assume random distribution of the nodes. To communicate end-to-end, ad hoc networks do not limit the number of hops to achieve communication. In fact, ad hoc networks are designed to be efficient for end-to-end connections across multiple hops. Scale-free network research has shown that this is not desirable. Instead, direct connections with very limited multiple hop connections are preferred as this is shown to be topologically more stable (from the view point of errors).

Dekker (2005) has performed simulations to compare the performance differences between ad hoc, random networks with those of scale-free networks, with emphasis on military context. The results are shown in Figure 2.

The parameter *p* is the Kawachi process parameter that determines the attachment behaviour of nodes in large networks. For *p* equal to unity, a random or distributed network is formed. (This is usually the ad hoc networking case.) For *p* greater than or equal to two, a scale-free network is produced. (For these cases, the networks have mostly direct connections not with each other, but communicate through hubs that have evolved to be optimal for connections.) It is shown in Figure 2 that the performance, determined by loss exchange ratios of two opposing forces, is better for the scale-free network compared to a random, fully distributed network (fully ad hoc).

The reason for the difference in performance is two-fold. First, the presence of "hubs" in scale-free networks facilitates direct links. Second, in the scenario, the links simulated are fairly high-speed links (relative to mobility).

The results indicate that ad hoc networking is a necessary condition but not sufficient for optimal connections of joint data links. Special algorithms that mimic the "preferential attachment" scheme of scale-free networks should be incorporated into ad hoc networks. If this condition is fulfilled, it is possible to achieve fault-tolerant, optimal ad hoc networks for joint data link operations. The results also mean that it may be more productive to focus on the creation of highly dynamic subnets with predominantly direct connections and possibly very few hubs of opportunity. In this case, ad hoc routing is not a dominant consideration. The ability to carefully select these "hubs" through algorithms is the key. Since these hubs carry the bulk of information, the subnets should preferably be broadband enabled.

The hubs themselves should then be ad hoc networked across a very "thin" backbone, suggesting that this backbone may not necessarily be itself broadband. The reason for this is that long range links have to be more robust and a trade-off between robustness and data carrying capacity is necessary. This concept is depicted in Figure 3.

Here is an explanation of the different components:

a. The "thin" backbone provides wide area coverage and trades off high data rates for longer range and wider coverage. It is also robust to possible interference.

b. The broadband local area network (LAN) is devised to be an ad hoc, peer-to-peer network so that the ability to form "hubs" temporally and spatially is facilitated. Furthermore, the links should be high capacity in nature; the higher capacity links ensure that local force elements are synchronised and function much faster to prevent attacks that could inflict harm on the system.

c. Both the "thin" backbone and broadband LAN can function independently of each other. However, should the need arise to leverage each other for extended and expanded situation awareness, common protocols and message translators can provide the means to connect seamlessly.

The "thin backbone" is accessible only to a select group of participants – the "hubs". This ensures low latency across very wide coverage and long ranges. Since this is a select group, there are fairly few participants. Second, the "thin backbone" has to be fairly flexible for technology insertion. This provides the possibility to remove the trade-off between data rate and range. In addition, new participants can be added. A "thin backbone" composed of software defined radios providing

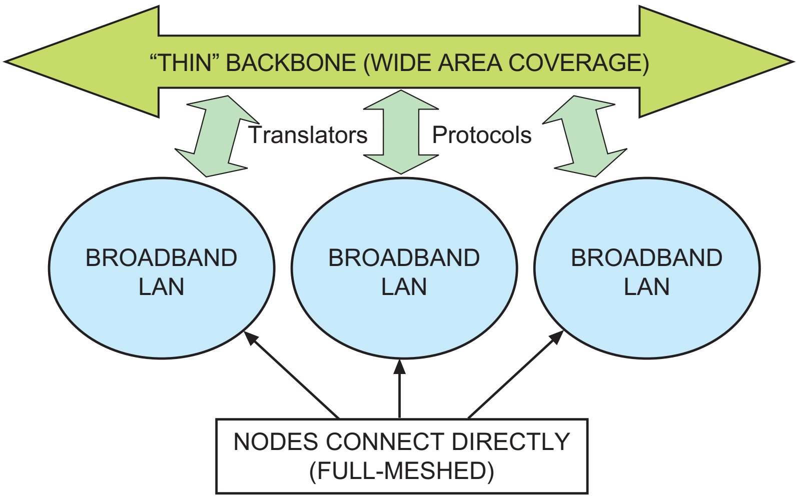

*Figure 3. Joint Data Link Architecture Concept*

flexibility of waveform and frequency should be optimal.

The broadband LAN shall increasingly comprise Commercial Off-The-Shelf equipment such as WiFi and WiMax, and be based on Internet Protocol adapted for military environment, frequencies and range. This creates the condition for maximum number of participants to be equipped with the same communications means. With mass proliferation, peer-to-peer connections and the exchange of information are assured. This is the commercial model – ubiquity drives connectivity.

In our architecture, "hubs" are gateway equivalents. Thus, our architecture also advocates more commonality and less gateways for optimal operations.

## CONCLUSION

There is currently no analytical template to compare different data link architectures for efficiency and effectiveness. Reasons for adopting any data link architecture are also not purely driven by technical merits alone. They have a lot to do with the alliances and hence, interoperability requirements for coalition operations. European countries, for example, have adopted two primary data links – Link 16 and Link 11 (22). This is to inter-operate with US forces and equipment. A second driver is legacy systems. Many countries have indigenous data links, i.e., Sweden's Ra-90, which are already in-service. These systems have to be taken into consideration when developing a data link architecture for joint operations.

Thus, we expect the above conceptual architecture, driven purely by technical factors, to evolve taking legacy systems and future defined coalition operations into account. A resultant architecture may then be different from what we have envisioned.

Another consideration is that any adversary will adapt to superior technologies using asymmetric strategies. From WWII to OIF and the Israeli-Hezbollah war, it has been proven that when faced with an overwhelming force, the adversary will disperse and conceal itself. Cordesman (2006) noted the limitations of intelligence, target and BDA against an adaptive enemy. Taylor (2005) made the same observation that current light ground and aerial surveillance is insufficient to gather intelligence on an adversary that adapts, disperses and conceals himself using knowledge of the surveillance capabilities of the US and other Western Countries. The US Army appears to have evolved its warfighting system to fight a dispersed enemy in line with the observations of Cordesman and Taylor long before the Afghan and Iraqi wars. The warfighting system is known as Future Combat System.

Because the adversary is intelligent and adaptive, and we should not assume otherwise, the data link system for joint operations must be designed to be capable of supporting future operations against fleet-footed, highly stealthy adversaries. Against such adversaries, the data link must support equally fleet-footed and stealthy sensors, i.e., soldiers on the ground. To be clear, it does not help to give a soldier a Link 16 terminal because of the form and fit. Thus, future data links must be "sized" appropriately for disadvantaged users or nodes, i.e., tactical unmanned systems. In this aspect, our architecture which advocates very few hubs (resource-rich) and many nodes (resource-poor) directly connected with these hubs strikes a good balance between performance, affordability and flexibility.

## REFERENCES

Chia, K. B., Tri, T. H, & Su, W. (2006). Simulation Of Physical And Media Access Control (MAC) Layer For Scalable Wireless Sensor Networks. NPS Thesis.

Close Air Support. (n.d.). Retrieved 15 October 2006 from http://en.wikipedia.org/wiki/Close_air_support

Cordesman, A. H. (2006). Preliminary Lessons of the Israeli-Hezbollah War. Centre for Strategic and International Studies.

Dekker, A. (2005, November). A Taxonomy of Network Centric Warfare Architectures. Presented at the SETE 2005 – Systems Engineering/Test and Evaluation Conference, Brisbane, Australia.

Dekker, A. (2005, December). Network Topology and Military Performance. Presented at the MODSIM 2005 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand.

Fiedler, D. M. (2004, March). HF Combat Net Radio Lesson Learned Again. In Army Communicator.

Grant, G. (2006, June). US Army May Scale Back UAV Plans. In C4ISR Journal.

Kirkpatrick, C. E. (2003). Joint Fires as They Were Meant To Be: V Corps and the 4th Air Support Operations Group During Operations Iraqi Freedom. Presented at AUSA 2004.

Kopp, C. (2004, March). NCW Buzzwords, Bytes, and The Battlespace. In Defence Today.

Murray, M. G. (2004). Aimable Air/Sea Rescue Signal Mirrors. The Bent of Tau Beta Pi. Retrieved on 4 December 2006 from www.tbp.org/pages/Publications/BENTFeatures/F04Murray.pdf

Scale Free Network. (n.d.) Retrieved 15th Oct 06from en.wikipedia.org/wiki/Scale-free_network.

Taylor C. D. (2005). Trading the Sabre for Stealth: Can Surveillance Technology Replace Traditional Aggressive Reconnaissance. Presented at AUSA 2005.

The Origins Of Blitzkrieg – WWI. (n.d.). Retrieved 15 October 2006 from www.bellum.nu/basics/concepts/blitzkrieg.html

## BIOGRAPHY

Dr Yeoh Lean Weng is Director (C4I Development) and concurrently, Deputy Director of Temasek Defence Systems Institute at the National University of Singapore (NUS). He received his Bachelor (with Honours) and Master of Science degrees from NUS in 1983 and 1987 respectively. He further obtained two Masters (Distinction) in 1990 and a PhD in Electrical Engineering in 1997 from the Naval Postgraduate School (NPS). He attended the Program for Management Development from Harvard University in 2003. He received the National Day Public Administration Medal (Bronze) in 2001, and the Defence Technology Prize in 1992 and 2004. Lean Weng has extensive experience in the development and implementation of command, control and communications systems.

Daniel Chia Kim Boon is Programme Manager (DSTA Masterplanning and Systems Architecting). He has been involved in the acquisition and R&D planning of communications and data link systems. He is currently responsible for data link system of systems architecting. He has a Master of Engineering and a Bachelor of Engineering in Electrical Engineering from NUS. He obtained a Master of Science (Electrical Engineering), specialising in communications, from the NPS in 2006.